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THE PROTEIN REQUIREMENTS OF ANIMALS INCLUDING MAN

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THE PROTEIN REQUIREMENTS OF ANIMALS INCLUDING MAN

By RICHARD J. BLOCK, Ph.D.*

Introduction

"The current trend of the investigation of the chemistry of nutrition is emphasizing the significance of the amino acids as the fundamental factors in all problems in which hitherto the role of proteins has been involved" (26, 32).

The large number of investigations in the field of protein and/or amino acid nutrition precludes an attempt to review all contributions in this paper. It is hoped to present some of the evidence suggesting that by and large, the pattern of amino acids required by different animals has many more similarities than differences. It seems that although the quantitative need for protein[1] (amino acids) in the diet is a function of the potential maximum growth rate of the animal, this growth rate being controlled by genetic factors, the *pattern* of the essential amino acids required is remarkably similar among the different animals. There are of course exceptions to this broad generalization which will be pointed out.

Proteins are synthesized by the living organism from 19 or so amino acids which are usually supplied in the form of dietary proteins. The dietary proteins after ingestion, are first broken down into their constituent amino acids by the enzymes of the gastrointestinal tract. The amino acids thus liberated are absorbed into the body. However, the hydrolytic enzymes and other tissue constituents which are involved in the digestion of food are also proteins and are also hydrolyzed in the G. I. tract to their constituent amino acids. In fact it may well be that the largest part of the amino acids absorbed from the intestine originates from the digestion of proteins secreted by the organism into its gut (Fig. 1). Thus the pattern of amino acids presented to the organism during digestion is almost, though obviously not entirely, constant (28, 29).

The absorbed amino acids are then recombined into the myriad of specific proteins of which the organism is composed. It should always be remembered that no protein can be made unless every amino acid of which it is composed is available at the site of synthesis. Furthermore, the quantity of protein which

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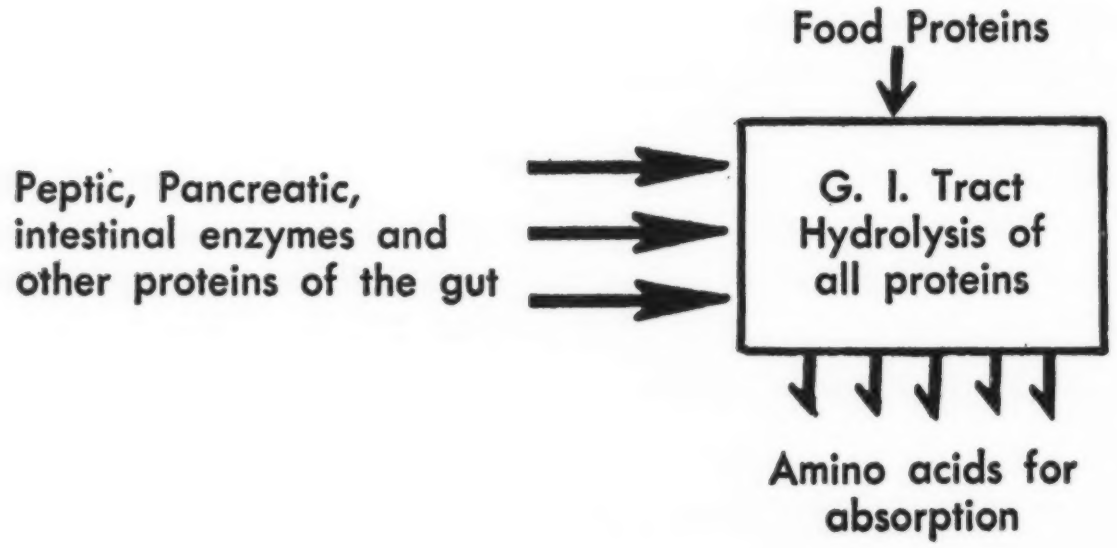
1 Protein nutrition or metabolism is used interchangeably with amino acid nutrition or metabolism in this paper.

FIGURE 1.

Diagrammatic representation of sources of amino acids supplied to the portal circulation.


Food Proteins
Peptic, Pancreatic, intestinal enzymes and other proteins of the gut
G. I. Tract Hydrolysis of all proteins
Amino acids for absorption

can be made is limited by that amino acid which is available in relatively the smallest amount (30, 31). This fact, generally accepted intuitively by nutritionists, has been demonstrated experimentally using amino acids labelled with isotopes. The isotope experiments appear to show that *all* the amino acids needed for the synthesis of a protein molecule must be lined up on the "template" and are then linked together by almost simultaneous dehydration to form the finished protein or, at least, that peptides are synthesized, which do not accumulate to any appreciable extent and these in turn are synthesized to the tissue protein (16, 18, 42). In either event protein synthesis is governed by the law of the minimum (26).

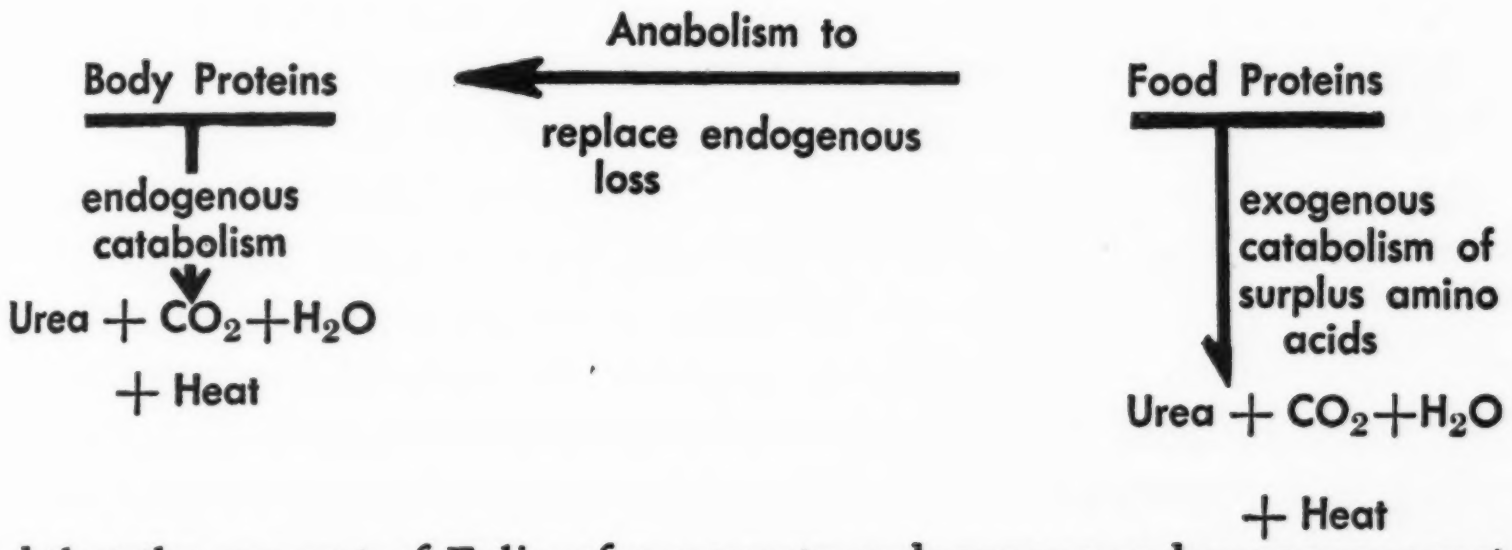
Approximately 50 years ago, Folin (13) promulgated the idea that there are two different types of protein metabolism, i.e. endogenous and exogenous metabolism. This was a remarkable step forward and really laid the basis for much of our present knowledge of protein nutrition. Folin (13) and Rubner (cf 24, 38) believed that the tissues of an adult body slowly waste away due to the "wear and tear" of living. For this purpose amino acids have to be supplied in the food to enable the organism to replace the lost protein. When an excess quantity of amino acids is ingested by the adult, these surplus amino acids are broken down to yield CO_2, H_2O, energy and urea. Where new tissue is being formed, such as during growth, tissue repletion, pregnancy and lactation, the demands for protein are obviously greater than in the metabolically quiescent adult where only the wear and tear quota needs to be replaced (Fig. 2).

The concept of Folin (13) was completely accepted for approximately 20 years until Borsook (9) and Schoenheimer (41), the latter using N^{15}, found that living tissues are not essentially metabolically inert; but that the tissue proteins are being constantly broken down to their constituent amino acids.

These amino acids then enter the body "amino acid pool" where they are mixed with amino acids coming from the digestive tract (Fig. 3). Schoenheimer believed that the amino acid turnover of tissues was exceedingly rapid

FIGURE 2.

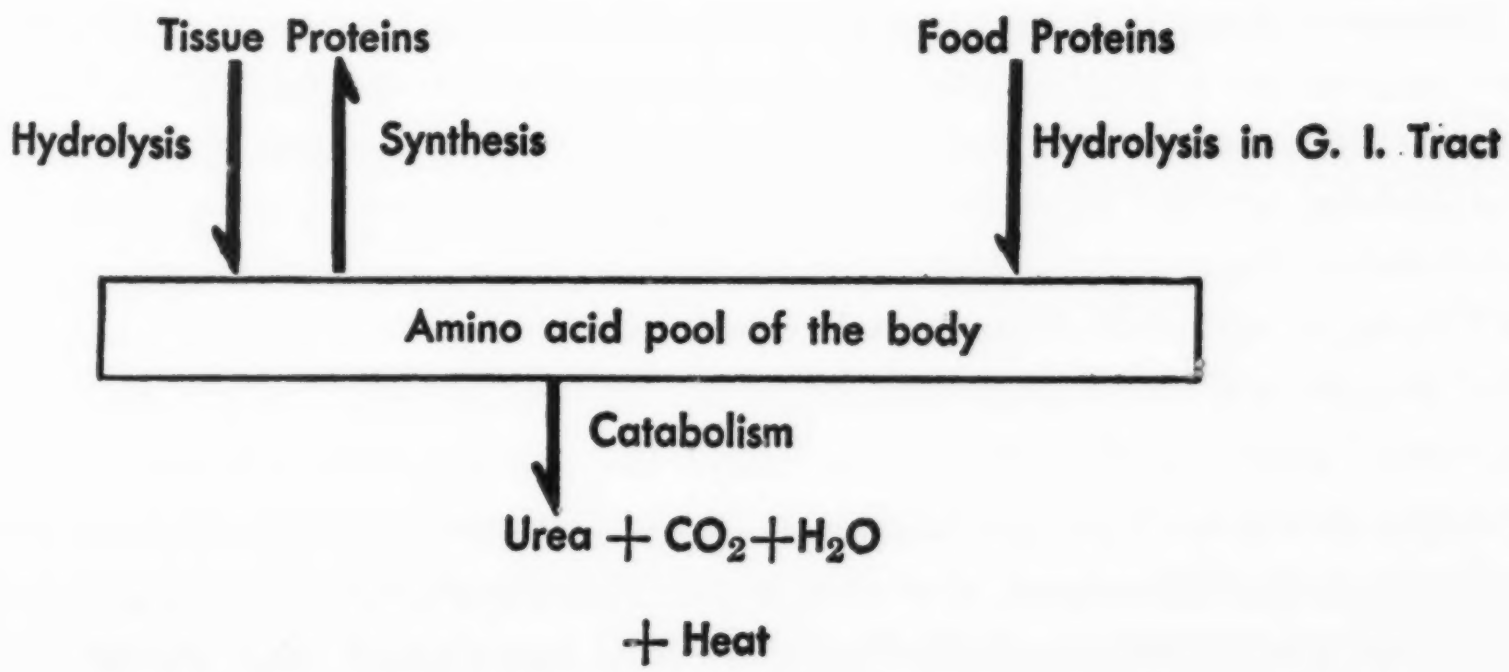
Diagrammatic representation of Folin's scheme of protein metabolism in the adult.



and that the concept of Folin of a separate endogenous and exogenous metabolism was completely erroneous. During the past 20 years many investigators have confirmed Schoenheimer's findings; namely, that each protein is being constantly hydrolyzed and resynthesized in living tissue. However, it has also been found that the rate of turnover is not uniformly rapid in all tissues. It is very fast in some (liver, intestinal wall) and very slow in others (muscle, brain) i.e. each protein has its characteristic turnover rate (42). The known

FIGURE 3.

Diagrammatic scheme of Schoenheimer's hypothesis of the dynamic equilibrium in protein metabolism.



facts of protein metabolism are explained by assuming that as the quantity of amino acids in the "pool" is increased above a certain maintenance level, the rate of their catabolism is increased to restore this level.

A point should be discussed which has been neglected in the interpretation of many isotope feeding experiments with intact animals which have been used to determine the half-lives of specific proteins and the size of the amino acid pool. The usual method is to feed labelled amino acids such as S^{35}-methionine, N^{15}-lysine, etc. and then to estimate the half-life of the protein by the change in its isotope concentration with time. In such experiments it is recognized that all the body proteins are labelled and in proportion to their turnover rates. These rates are assumed to be relatively constant and so the supply of isotope to the amino acid pool from all the tissues for synthesis of the protein under investigation is also constant. This thinking neglects the contribution made by the proteins secreted into and digested in the G. I. tract. If, as appears likely at present, the greatest part of the amino acids reaching the portal circulation and hence the body amino acid pool is derived from the gastrointestinal tract; then the quantity of isotope supplied to the pool will vary with amount and type of gastrointestinal secretion which in turn is influenced by the components of the diet.

In connection with the usual thinking of Schoenheimer's experiments and the interpretation of the results of feeding isotopic amino acids, just two experimental findings can be recalled: Ruminants were fed $Na_2S^{35}O_4$ and the cystine and methionine was isolated from the serum albumins, the milk proteins and the proteins of the microorganisms of the rumen. Serum albumins contain Cys and MET in the ratio of 6:1; milk proteins have a Cys:MET of 1:3 and the proteins of the rumen contents have a Cys:MET ratio of 1:1. It was found that the specific activity of the sulfur both in the cystine and in the methionine isolated from the serum albumins, the milk proteins and the rumen proteins was the same (7). Because the ratio of Cys:MET in the entire animal is approximately 1:3 (6), the specific activity of methionine S would be expected to be about one-third that of the cystine S. The experimental findings clearly showed that when cystine and methionine were absorbed in equal amounts with equal specific activities, then no detectable differential dilution was effected in the "amino acid pool" of the body. This finding was not anticipated if the amino acid pattern of the "body pool" is similar to that of the entire organism. Therefore, the results of these experiments suggest that the amino acid pattern of the "body pool" is more nearly that of the gastrointestinal tract rather than that of the body.

The second experimenal observation is that of Monod (20). Bacteria were cultured on a radio-active substrate until all the proteins were radio-active. The organisms were then cultured in "cold" medium under conditions which induced the formation of a *new* enzyme. The newly induced enzyme was apparently without radio-activity and hence could not have been synthesized from pre-existing labelled proteins in the organism. Monod (20) says "there seems to be at present no conclusive evidence that the protein molecules within the cells of mammalian tissues are in a dynamic state. . . . it seems necessary to conclude that the synthesis and maintenance of proteins within growing cells is not necessarily or inherently associated with a 'dynamic state'."

Although Monod's interpretation of his experiments with rapidly growing bacteria cannot be applied without modification to slower growing or adult animals for which there is ample evidence for the continuing hydrolysis and synthesis of proteins; the importance of the amino acid pattern of the gastrointestinal tract in the interpretation of results of feeding isotopically labelled amino acids to intact animals is apparent.

To recapitulate: In the the living animal, there is a continuous turnover of protein. Thus, the proteins of the living cell are being constantly broken down (wear and tear) and new protein molecules are being rebuilt in part from amino acids recovered from the hydrolysis of previous tissue proteins, especially those of the gastrointestinal tract; in part from the amino acids of the diet. The process of tissue breakdown and regeneration results in the irreversible destruction of some of the amino acids. The extent of this destruction is indicated by the quantity of nitrogen in the urine. The amino acids so destroyed must be replaced by the dietary proteins or be synthesized in the body from certain other nitrogen-containing compounds (ammonia, glutamine and other amino acids, etc.) and from non-nitrogenous substances.

If amino acids are lacking in the food, catabolism results in the reduction of the amino acid supply of the body which is reflected in a decrease in the quantity of tissue proteins. It appears that the greater the magnitude of the tissue proteins, the greater the supply of tissue amino acids which can be used for energy and for the maintenance of essential functions. This tissue protein storehouse is an important factor during periods of metabolic stress. The catabolism of amino acids to form urea and other waste products is continuous, the amount being high when the protein stores and metabolic activity are high, and low when the stores and activity are low. Evidence is accumulating which indicates that high protein stores with concomitant high catabolic activity give energy and reserves to meet the stresses and strains of living (1).

Protein Requirements from Growth and Repletion Studies

ESSENTIAL AMINO ACIDS

Around the turn of the last century, Thomas Burr Osborne, at the Connecticut Agricultural Experiment Station, observed that the amino acid composition of some purified proteins differed rather markedly from other purified proteins. Recognition of the differences which exist in the composition of proteins directed attention to possible differences in the nutritive value of zein from corn which appeared to be devoid of lysine and tryptophan compared to that of casein from milk, a rich source of these two amino acids. About 1910, Osborne sought and obtained the collaboration of his good friend, Professor Lafayette B. Mendel of Yale who was, even then, one of the most outstanding American physiological chemists (35).

At a time when there was but fragmentary knowledge of the dietary needs of animals for growth, Osborne and Mendel conclusively demonstrated that both tryptophan and lysine were indispensable dietary components. The large body of experiments carried out by many investigators both here and abroad, will not be reviewed except to remind you that from the brilliant investigations of Professor William C. Rose (36, 37) we now know not only which amino acids need be supplied in the diets of non-ruminating animals, but potentially we are also able to determine the quantities of each essential amino acid needed for different animals at various times in their life cycles. The studies conceived and originated by Osborne and Mendel, and brought to a successful conclusion by Rose, have been of great practical benefit to mankind. Furthermore, I think that the benefits so far realized will be dwarfed by the continuing use of their results in the future.[2]

As a result of numerous investigations, the amino acids may be classified into three groups (5, 8) as shown in Table I. The absolute quantities of these essential amino acids which must be supplied in the diet will change with the species of animal and will vary rather widely with the physiological state of the animal and among various groups in the same species. For example, the lysine requirements of the growing rat or the animal which has been depleted of protein is approximately 15 times as great as the need for lysine by the healthy adult animal. When an animal is depositing new proteins in its own structure or supplying protein to a parasitic organism, its protein (i.e. essential amino acid) requirements are higher than if the animal is only required to make up for its daily metabolic deficit. The striking thing, however, is that there is such a large difference between growth or repletion re-

2 The possibility of supplementing deficient indigenous diets with synthetic essential amino acids is beginning to receive attention (4, 12, 22, 43, 46).

TABLE I.
Nutritive Classification of the Amino Acids

Essential (Indispensable)	Semi-indispensable	Non-essential (Dispensable)
Histidine	Arginine*	Glutamic Acid
Lysine	Tyrosine†	Aspartic Acid
Tryptophan†	Cystine†	Alanine
Phenylalanine	Glycine*	Proline
Methionine (+ Serine or Glycine)	Serine*	Hydroxyproline
Threonine		
Leucine		
Isoleucine		
Valine		

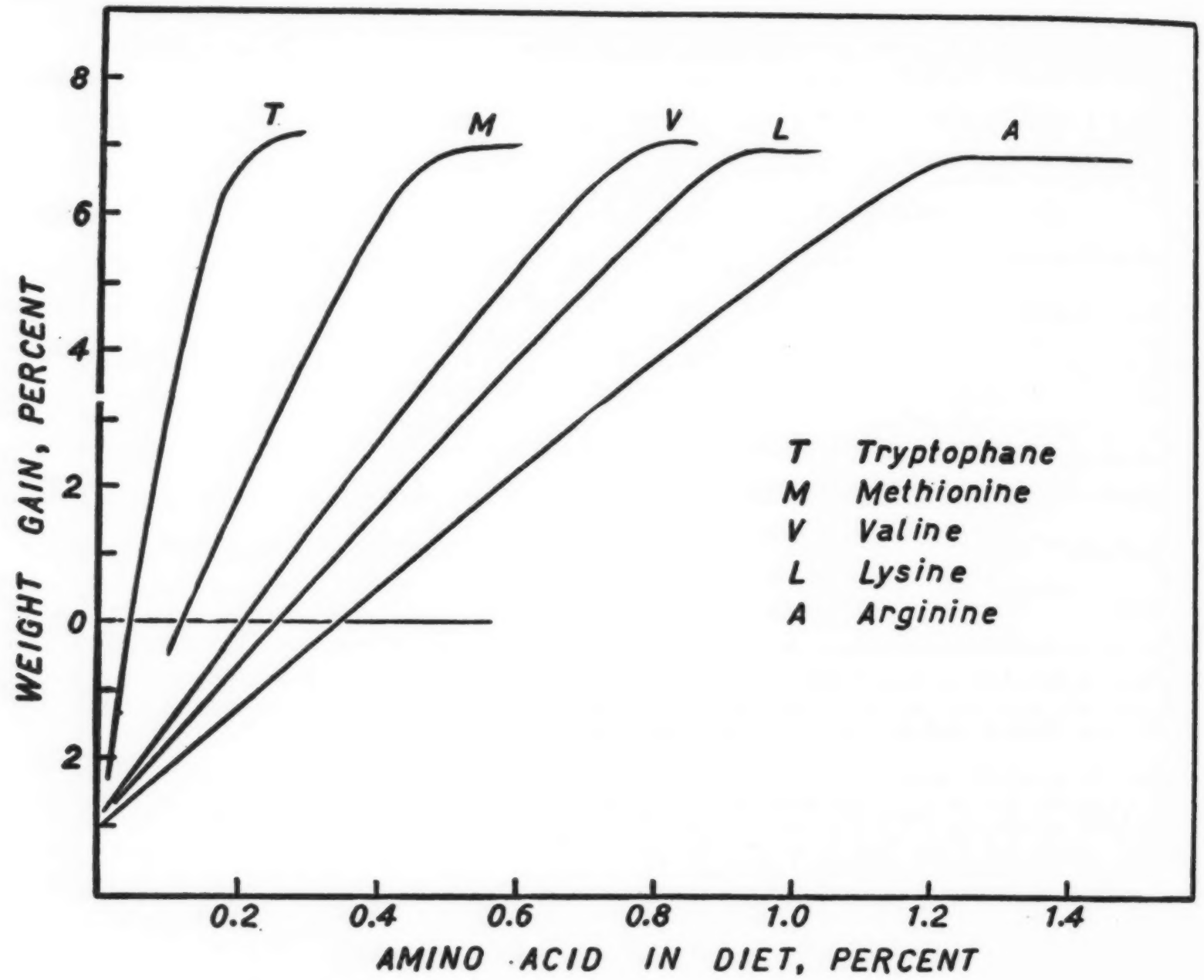
*Arginine and glycine are essential for chicks and turkeys. Serine will spare or replace glycine.
†Tyrosine will spare but not completely replace phenylalanine. Cystine will spare but not completely replace methionine. Nicotinic acid will spare but not completely replace tryptophan.

quirements for a certain amino acid and its maintenance needs. The differences of 15-fold for the lysine needs of the rat mentioned above may be the exception rather than the rule. However, these findings do emphasize the fact that all the quantitative data which will be presented shortly must be viewed within the frame of the experimental conditions and not extrapolated to other phsiological states of the same animal, let alone to other species.

Almquist (cf 8) has pointed out that as the deficiency of an essential amino acid in the diet becomes more severe, animals may begin to lose weight. The loss of weight, however, appears to be merely an extension of the growth processes into the zone where the loss of protein is greater than its formation. An illustration of these facts is given in Fig. 4. The growth curves are continuous downward toward a common negative rate of gain at complete deficiency of any amino acid. The shape of these growth curves seems to denote a continuation of the same fundamental process which is in operation at positive growth rates i.e., (1) the amount of tissue synthesized is proportional to the supply of the essential amino acid, and (2) tissue loss is relatively independent of the supply of amino acid (cf. discussion of Folin and Schoenheimer hypotheses above). It appears that the true zero point of growth should be represented by the point of maximum weight loss and not by the point of zero gain. In fact the latter may require as much as 30 per cent of the total amino acid needed for maximal gain in weight.

FIGURE 4.

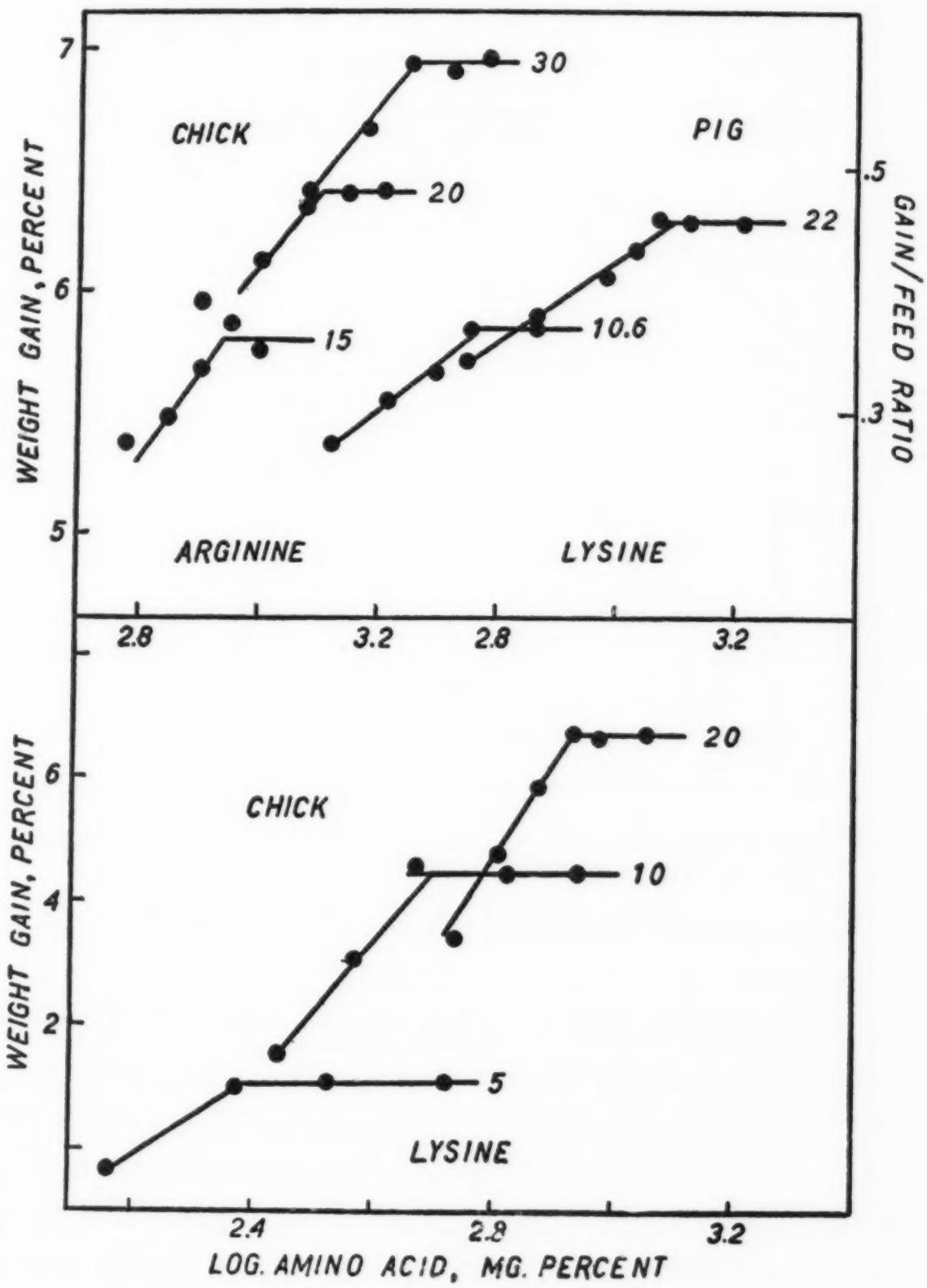
The relation of the daily weight gain of chicks to the percentages of certain essential amino acids in the diet (from Almquist, 8).



The results obtained from feeding diets deficient in a single amino acid are logically interpreted on the basis of the Law of Diminishing Returns. Thus, feeding increasing quantities of lysine to an animal on a lysine-deficient ration results in constantly diminishing increments of biological response with increases in the essential amino acid until additional amino acid no longer results in increased rate of growth. When the limit of maximal response is well defined, as by a plateau in the data, the minimal requirement for the essential amino acid is readily perceived from the intersection of the response and the plateau lines. A valuable feature of the logarithmic method is that full weight is given to submaximal growth responses. Fig. 5 illustrates several examples of the application of this principle to amino acid requirement. This figure shows the relation both of the daily rate of gain in weight of chicks and the gain:feed ratio of young pigs to the logarithm of an amino acid level in the diet at different livels of total dietary protein. Several points should be noted: 1. There is a linear relation of the rate of growth to the logarithm of the amino acid level. 2. This relation reached a different plateau with each

FIGURE 5.

The relation of daily rate of weight gain of chicks, and the gain:feed ratio of young pigs, to the logarithm of an amino acid level in the diet, at different levels of protein. Per cent of protein is indicated at the ends of each curve (from Almquist, 8).

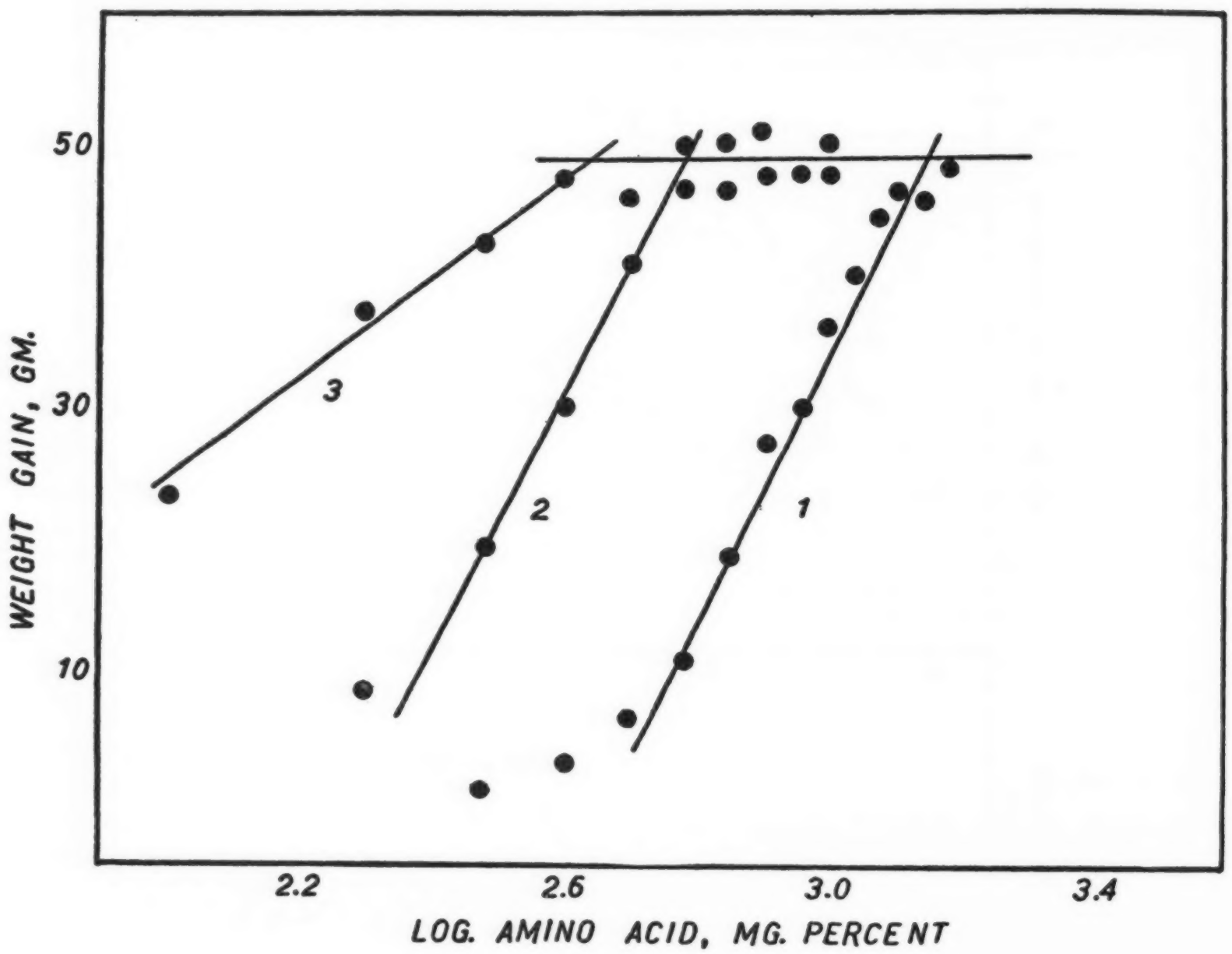


level of protein. 3. A deficiency in an essential amino acid gave the same net result as a deficiency of protein. 4. The requirement of an essential amino acid is increased with increasing total protein intake (from Almquist 8, cf 15).

Fig. 6 illustrates the sparing action of tyrosine on the quantity of phenylalanine needed by the rat. The data taken from Armstrong (2) are plotted similarly to those in Fig. 5. Curve 1 shows the growth response to phenylalanine in the absence of tyrosine; Curve 2, the growth response to phenylalanine when 1 per cent tyrosine was present in the ration; while Curve 3 shows the response to various quantities of tyrosine when 0.6 per cent of phenylalanine

FIGURE 6.

The sparing effect of tryrosine on the phenylalanine requirements (Recalculated from Armstrong, 2).



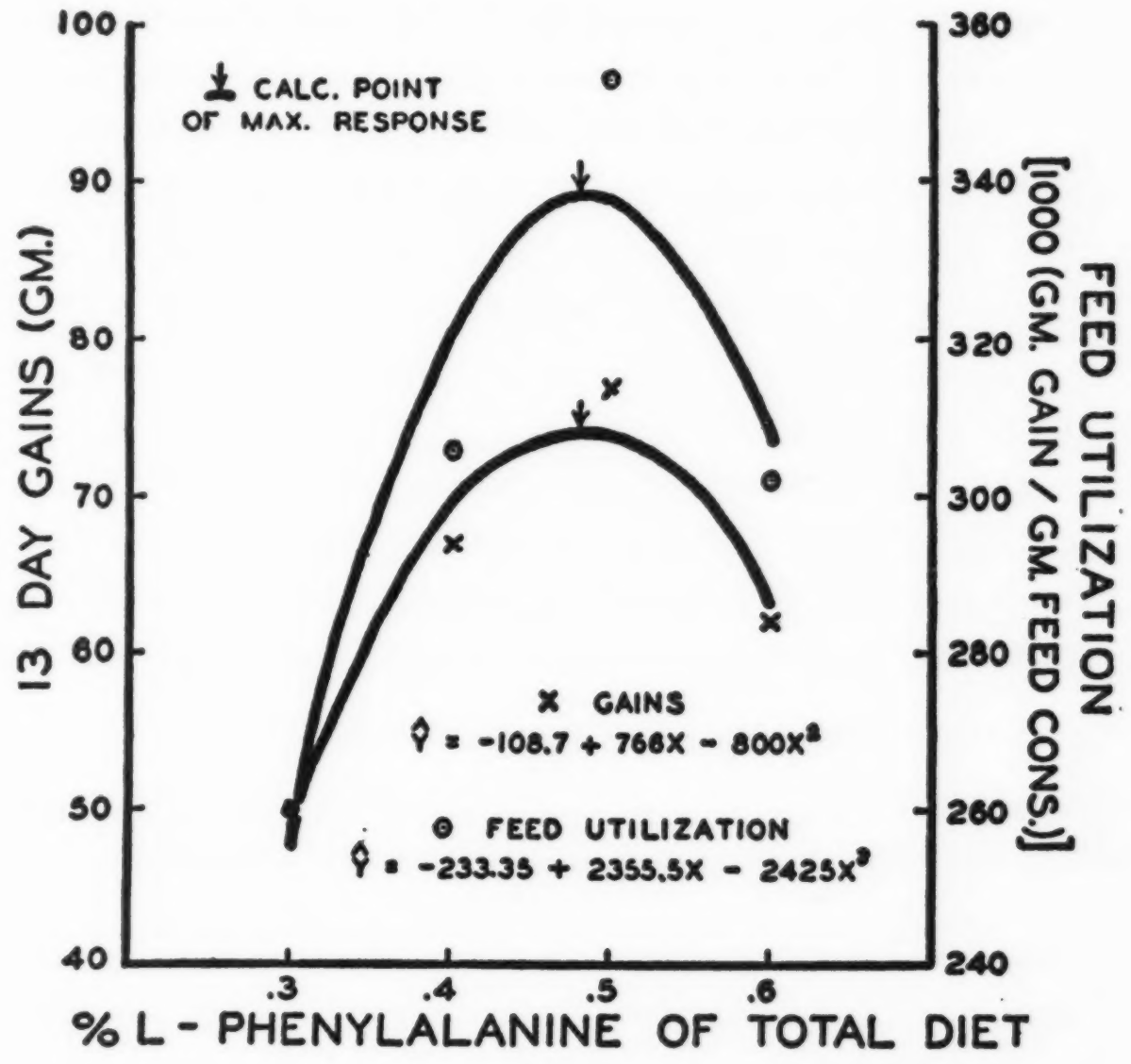
was present. These results indicate that in the absence of tyrosine, the rat requires 1.32 per cent (i.e. antilog of 3.121) of phenylalanine; when excess tyrosine was present, only 0.60 per cent of phenylalanine was needed. When 0.60 per cent of phenylalanine (Curve 3) was present, maximal growth was obtained with only 0.42 per cent of tyrosine. From these data, it appears that 72 parts of phenylalanine are needed by the rat to synthesize 42 parts of tyrosine. As the theoretical yield of tyrosine from phenylalanine is 110 per cent, these results indicate that the conversion of phenylalanine, an essential amino acid, to tyrosine, a semi-essential amino acid, is only approximately 50 per cent efficient.

Fig. 7 from Fisher (11) shows the effects of varying the level of L-phenylalanine on the growth of chicks. Attention is called to the fact which was suggested some years ago (23) but only recently widely accepted (14, 17, 40) that an excess of some amino acids can also cause a decrease in the rate of growth.

The available data indicate that the protein requirements for tissue growth

FIGURE 7.

Growth and feed utilization curves as functions of the level of L-phenylalanine in the diets of chicks (from Fisher, 11).



are most economically achieved when the dietary furnishes the required quantity of balanced protein (4). By balanced protein is meant the condition in which the essential (and probably the semi-essential) amino acids are each present in optimal ratios to each other for the highest efficiency of utilization for new tissue formation and for repair of worn-out tissues and in which there is a sufficient quantity of the non-essential amino acids to prevent any metabolic diversion of the essential amino acids from their tissue-building function.

In practice this means that the nutritive value of a mixture of dietary proteins with a partial deficiency of one essential amino acid is limited to that fraction of the protein which is available for the closest attainable balance. If the single deficient amino acid is present at X fraction of requirements for balance, then approximately X fraction of the deficient proteins are usable for growth. Thus, increasing the *amount* of this imbalanced protein in the diet will increase the quantity of "balanced protein" which is available and may permit faster tissue formation.

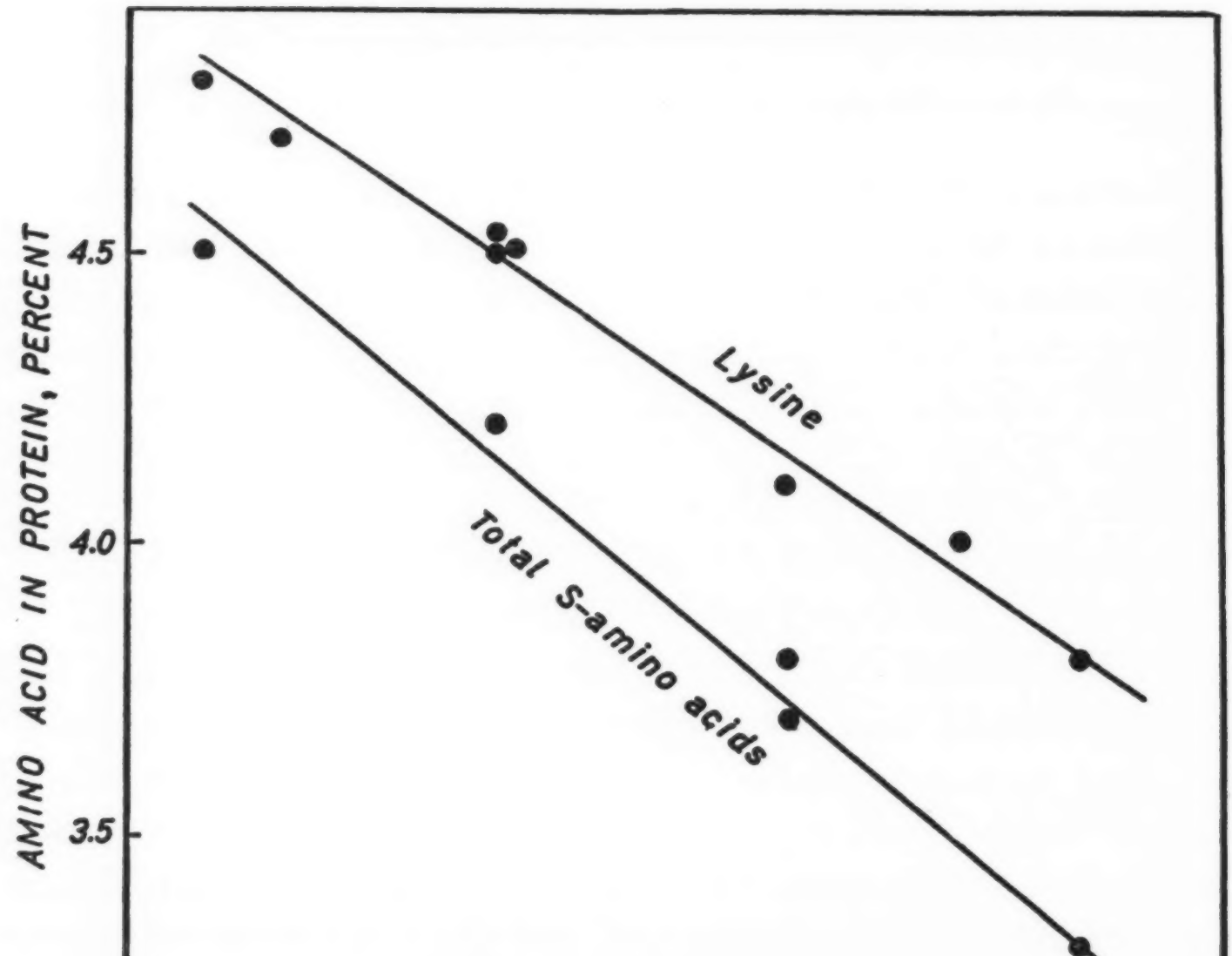
There is, however, some evidence that, as the gross protein level of the diet is raised, the percentage of each essential amino acid required *in the protein* may decrease, even though the percentage of that amino acid in the

diet must be increased. The effect of increasing the protein intake on the amino acid composition of the dietary protein is illustrated for lysine and for the sulfur amino acids in Fig. 8 (from Almquist, 8, cf 15).

This figure shows that the percentage of essential amino acids required in the dietary protein of chicks decreases with increasing total protein intake. It is for this reason that humans and animals have survived for so long on diets of proteins which are rather poorly balanced with respect to their amino acids. However, there are limits to which an unbalanced protein can be eaten in order to overcome its amino acid deficiency. Obviously if a protein is completely devoid of an essential amino acid, as are gelatin or zein, for example, no amount eaten will furnish materials for protein synthesis. Even if the protein is markedly deficient in a single amino acid, e.g. the lysine deficiency of wheat gluten, optimum nutrition is never obtained no matter how much wheat protein is fed and in fact the rate of growth first increases, reaches a maximum, and then decreases as successive additions of gluten are fed (3).

FIGURE 8.

The relation of the optimal percentage of lysine and of cystine and methionine in the protein to the level of protein in the diet (from Almquist, 8).



This is in contrast to the results obtained by feeding increasing quantities of adequately balanced or slightly inferior proteins. In these cases, the rate of growth rises to a maximum and remains there even when 90 per cent or more of the calories are derived from protein.

Protein Requirements from Studies on Nitrogen Balance

The discussion so far has been largely concerned with protein needs for new tissue formation, i.e., growth, repletion, pregnancy and lactation. Mention, however, was made that the amino acid requirements for maintenance may differ markedly from those for growth. Maintenance protein requirements are usually studied by the nitrogen balance method. Nitrogen balance is the difference between nitrogen intake and nitrogen excreted. If the nitrogen intake is greater than the nitrogen excreted, then the organism is gaining protein and is in positive balance. If the nitrogen intake is less than the nitrogen excreted, then the animal is losing protein and is in negative balance. Only if the nitrogen intake equals that excreted, is the organism in protein equilibrium. However, the *quantity* of dietary protein needed to maintain nitrogen equilibrium will vary with the magnitude of the protein stores as well as with the amino acid composition of the dietary (1, 25). Thus, the protein requirements for nitrogen equilibrium are influenced by the dietary history of the animal. In fact, it appears that potential anabolic activity increases as the organism is depleted in protein stores and that different patterns of amino acids (i.e. different proteins) may have different functions in repletion, some promoting the filling of one store more than another. This observation may be also related to the gastrointestinal secretions.

Adjustment of the organism to a state of nitrogen equilibrium on diets low in balanced essential amino acids, may simply mean that the protein stores are depleted to such an extent that the body continues in a depleted state. To complicate the situation even more, it is possible for an organism to be in positive nitrogen balance and yet be losing nitrogen from some tissues.

These points are brought out in order to stress the severe limitations of our present knowledge of the amino acid requirements of man and other animals, especially those based on nitrogen balance experiments. The values to be presented must be considered in the light of these inherent weaknesses. Nevertheless, knowledge of the qualitative and quantitative needs for the essential amino acids based upon nitrogen balance studies have allowed great strides to be made in the practical feeding of farm animals and have indicated methods for improving the diets of humans in depressed areas using foods which are actually or potentially available (46).

Protein Requirements Based upon the Analysis of the Carcass for Amino Acids

A naive approach to the investigation of the amino acid pattern required by an animal is to analyze it for its composition of amino acids. This was first attempted by the author over 10 years ago (6, cf 30). In these studies, entire rats aged 2 days, 23 days, 100 days and 18 months old were analyzed. Also a group of old rats which had been maintained on a protein-free ration until they had lost one-half of their initial weight were studied, but the values are not included in the table. These and some of the later studies by other investigators (34, 39, 45) on rats, pigs and chicks are given in Table II. This table also shows the currently accepted amino acid requirements of these animals. All in all the conclusions based upon carcass analysis are not too different from those of the experimentally estimated findings. In view of the discussion above, better evidence of the pattern of amino acids required may,

TABLE II.
Comparison of Carcass Analysis and Dietary Requirements

	Amino acid values as gm. per 16.0 gm. of nitrogen										
	RATS						YOUNG PIGS		CHICKS		
	Carcass composition						Carcass composition	Dietary need	Carcass composition		Dietary need
	2 days	23 days	100 days	540 days	Adult	Dietary need					
Arg.	6.2	7.1	7.1	7.3	5.9	1.0	7.1	1.5	6.6	6.7	6.0
His.	2.8	2.3	1.8	1.7	2.2	2.0	2.7	2.0	1.8	2.0	1.5
Lys.	6.1	6.5	5.6	6.5	7.6	5.0	8.6	5.5	6.6	7.5	4.5
Tyr.	3.0	3.4	3.1	3.2	2.9		2.6		2.5	2.9	
Phe.	3.5	4.3	3.8	4.3	3.7	3.5	3.8	3.5	4.2	4.0	4.5
Try.	0.8	0.8	0.7	0.8	0.8	1.0	0.7	1.0	1.0	0.8	1.0
Cys.	1.3	1.7	1.4	1.4	1.5	1.5	1.0			1.8	
Met.					1.7	2.0	1.8	2.0	2.0	1.8	2.3
Thr.					3.9	2.5	3.8	3.0	4.4	4.0	3.0
Leu.					6.5	4.0	7.1	6.0	7.2	6.6	7.0
Iso.					3.5	2.5	3.8	3.0	4.3	4.1	3.0
Val.					5.5	3.5	6.0	3.0	5.0	6.7	4.0
Gly.										10.1	7.5

possibly, be obtained from analysis of the contents of the gastrointestinal tract.

Non-Essential or Dietary Dispensable Amino Acids

Thus far, little mention has been made of those amino acids which may be synthesized *de novo* by the animal from sources of nitrogen and carbohydrates or fats. In this connection the semi-essential amino acids (cystine and tyrosine) are to be excluded. Although the non-essential amino acids are just as important for the organism as the essential amino acids for the production of new tissues or the repair of "worn-out" proteins, it is doubtful if there is ever a deficiency of the non-essential amino acids when sufficient essential and semi-essential amino acids are supplied, provided the total nitrogen intake is adequate. Therefore, these will not be commented upon further.

Quantitative Data

In order to give numerical expression to some of the points discussed, the following tables are presented:

Table III lists the percentages of protein in diets usually recommended or employed for various animals. No attempt has been made to list all the animals which have been studied, but it is believed that sufficient data are given to indicate that there is a definite correlation between rate of growth and the

TABLE III.
Quantities of Protein Consumed by Various Species

	% in Dry Diet			
	Baby	Growing	Adult	Pregnancy Lactation
Humans	16	13	3*	17
Dogs	17	17	6.5*	17
Swine	18	14	12	
Rats	18	12	3*	6*
Minks	26			22
Ruminants	33	0	0	0
Chickens	21			16
Turkeys	28	20		16
Ducks	24	24		16

*Minimum

percentage of protein required, i.e., the faster growing animals need a higher percentage of protein. As the growth rate decreases, the quantity of protein, or more correctly the ratio of protein calories to total calories, diminishes and in the case of adults may be decreased very significantly. Obviously, once the rumen flora are established in a cow, her dietary protein requirements disappear.

Table IV summarizes some data on the amino acid requirements as per cent of the diet of certain young and adult animals. It should be recalled that glycine, arginine and possibly one or two other amino acids are necessary dietary components for poultry as well as those amino acids required by mammals. The need for a greater percentage of amino acids in the diet with increasing protein content is seen in the results on turkeys fed 24 per cent and 28 per cent protein, respectively. Table IV also shows that the amino acid requirements for adult animals may be but a fraction of the needs for

TABLE IV.

Approximate Requirements of Essential Amino Acids When All Other Amino Acids are Present in Adequate Amounts.

Calculated as Per Cent of Diet (from 8)

	Rat		Pig	Dog	Human	Chicken		Turkey	
	Young	Adult	Young	Adult	Adult	Young	Adult	Young	Adult
Approx. Protein Level %	20	10	13	6.5	10 ?	20	15	24	28
Arg.	0.2	0 ?	0.3	0.4	0.0	1.2		1.4	1.6
His.	0.4	0.1	0.4	0.1	0 ?	0.3			
Lys.	1.0	0.2	1.1	0.5	0.6	0.9	0.5	1.3	1.5
Try.*	0.2	0.1	0.2	0.1	0.2	0.2	0.15	0.22	0.26
Phe.*	0.9	0.2	0.7	0.6	0.9	0.9			
Cys. + Met.*	0.8	0.3	0.8	0.5	0.9	0.5	0.3	0.8	0.9
Thr.	0.5	0.3	0.6	0.5	0.4	0.6			
Leu.	0.8	0.3	1.2	0.8	0.9	1.4	1.0		
Iso.	0.5	0.5	0.6	0.5	0.6	0.6	0.5	0.7	0.8
Val.	0.7	0.4	0.6	0.7	0.6	0.8			
Gly.*	0	0			0	1.5		0.9	1.0

*The numerical values for tryptophan, phenylalanine, methionine and glycine may, in certain instances, have to be modified due to the failure of the investigators to take account of niacin, tyrosine, cystine, and serine in the experimental diets.

growth. This would suggest that, contrary to prevailing dietary practices in many countries where there are chronic protein deficiencies, adult men and older women should receive the smallest proportions of the available protein. However, the information on the amino acid requirements of infants, which is currently available, indicates that the pattern of essential amino acids required is similar to that of adults (21, 33), although the absolute needs are 8-10 times higher.

Table V presents some of the results shown in Table IV in a different

TABLE V.

Comparison of the Approximate Amino Acid Requirements of Various Animals*
Tryptophan calculated as unity

	Rat		Pig	Dog		Human		Chicken		Turkey	Bee
	Young	Adult	Young	Young	Adult	Young	Adult	Young	Adult	Young	Young
Arg.	1.0	0.?	1.5	3.7	4.0		0	6.0		6.1	3.0
His.	2.0	1.1	2.0	2.4	1.0		0 ?	1.5			1.5
Lys.	5.0	2.0	5.5	5.8	5.0	3.0	3.2	4.5	3.3	5.8	3.0
Try.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Phe.	4.5	2.2	3.5	9.0**	6.0		4.4	4.5			
Cys. + Met.	4.0	3.0	4.0	2.9 ?	5.0		4.4	2.3	2.0	3.5	
Thr.	2.5	2.8	3.0	3.4	5.0 ?	2.0	2.0	3.0			3.0
Leu.	4.0	2.8	6.0	8.2	8.0		4.4	7.0	6.7		4.5
Iso.	2.5	5.4	3.0	5.0	5.0		2.8	3.0	3.3	3.1	5.0
Val.	3.5	3.7	3.0	5.7	7.0 ?		3.2	4.0			4.0
Gly.	0	0					0	7.5			

cf Footnote Table IV.

*A mammalian tissue culture requires the following ratio of amino acids (tryptophan at unity):
Arg. 8.7; His. 1.6; Lys. 7.3; Tyr. 6.3; Try. 1.0; Phe. 3.3; Cys. 2.4; Met. 5.2; Thr. 5.9; Leu. 6.6; Iso. 2.0; Val. 5.9 (10, cf 27).

**Includes tyrosine.

manner i.e. the amino acids are calculated using tryptophan as unity. This procedure will exaggerate the errors in the estimation of the other values by the error incurred during the determination of the tryptophan requirements. However, as the tryptophan content of many dietary proteins and of animal carcasses is close to 1 per cent, this method of presentation offers certain advantages in a table of comparisons[3]. The values in Table V show that the

[3] However, amino acid ratios calculated with tryptophan at unity have no greater significance than those calculated on any other basis.

pattern of amino acids required by rats, pigs, dogs, humans, chickens, turkeys, and honey bees is similar. Poultry require more arginine and relatively large amounts of glycine. The need for more arginine by birds appears to be the result of their rapid growth because guinea pigs also require more arginine than the slower growing mammals (19), while the very slowly growing human infant probably does not require any dietary arginine. The need for glycine may be a reflection of the high rate of synthesis of uric acid which replaces urea as the compound used to dispose of nitrogen.

Several observations emerge from the comparison shown in Table V:

1. Although the absolute need of the human infant per kg. of body weight may be 8-10 times that of the adult, the ratio of the amino acids needed for

TABLE VI.

Daily Protein Intake and Pattern of Essential Amino Acids which Apparently Results in Nitrogen Equilebrium as Consumed by Various Racial Groups (from 8, cf 44).

Amino Acids are Calculated in gm. per 16.0 gm. N

	United States									
	Middle class Rural average	Poorest class Urban average	N_2 Equilibrium Experimental diets Range	Army emergency	Pregnant Women Conventional	Pregnant Women Ovolacto-vegetarian	Self-selected Women		Average U. S. pattern	
Protein* gm/day	95	74	25-30	40	65	52	65	70	As eaten	Try. calcu. at unity
Arg.	5.7	5.4	4.8-7.2	6.6	5.1	5.1	5.4	4.6	5.5	4.6
His.	2.3	2.3	2.0	2.4	2.3	3.1	3.2	2.5	2.5	2.1
Lys.	5.8	5.4	3.2-5.6	7.0	6.3	6.9	8.6	8.1	6.3	5.3
Try.	1.3	1.2	1.0-1.6	1.5	1.1	1.3	1.2	1.0	1.2	1.0
Phe.	5.5	5.5	4.4-5.6	6.3	4.3	6.0	4.0	4.1	5.1	4.3
Cys. +										
Met.	4.1	4.1	3.0-7.6	6.4	2.8†	2.9†	2.6†	3.1	4.7	3.9
Thr.	3.9	3.8	2.0-4.8	4.3	4.5	5.0	4.0	3.4	4.0	3.3
Leu.	9.0	8.8	4.4-6.8	9.2	8.3	10.2	8.0	7.5	8.0	6.7
Iso.	6.0	5.7	2.8-5.2	7.7	5.4	6.4	6.2	5.4	5.6	4.7
Val.	5.9	5.7	3.2-5.2	7.2	5.8	7.3	6.2	6.0	5.8	4.8

*Protein calculated from N x 6.25.
†Met. only.

TABLE VI. (cont'd)

	Other Countries							
	Algeria average diet	Chile average diet	Egypt average diet	Japan Rural	Java average diet	Nigeria average diet	Average pattern of six non-European countries	
Protein* gm/day	51	69	74		46	74	As eaten	Try. calculated at unity
Arg.	4.7	5.2	5.4		6.5	4.9	5.3	4.4
His.	2.2	2.3	2.4		2.3	2.3	2.3	1.9
Lys.	4.0	4.5	3.8	5.2	4.3	3.1	4.1	3.4
Try.	1.3	1.3	1.1	1.2	1.2	1.1	1.2	1.0
Phe.	4.9	4.8	4.9		5.0	4.1	4.7	3.9
Cys. + Met.	1.6†	1.9†	1.7†	3.6	1.9†	1.8†		
Thr.	3.4	3.6	3.6	3.9	4.0	3.8	3.7	3.1
Leu.	7.9	7.5	9.8	7.5	9.6	9.6	8.7	7.3
Iso.	4.6	4.6	4.5	5.9	4.4	4.3	4.7	3.9
Val.	5.1	5.1	5.3	4.9	5.9	5.3	5.3	4.4

*Protein calculated from N x 6.25.
†Met. only.

growth and for maintenance appears to be the same, at least for the few amino acids for which data are available. If further experimentation confirms these preliminary conclusions, then it appears that the amino acid pattern required by humans throughout life is constant[4].

2. In contrast to the above, the amino acid pattern, relative to tryptophan at unity, required by the young rat differs markedly from that of the adult. This is over and above the approximately six-fold difference in the protein content of the diet (cf Table III). There appear to be significant differences in the requirements for all the essential amino acids except threonine and valine. Note especially the 2.5-fold difference in lysine needs. Thus, the young rat requires approximately 15 times as much dietary lysine as does the adult.

The differences in the lysine requirements of humans and rats may be a reflection of the relative rates at which muscle protein, which is high in lysine, is being synthesized; and, in the case of the adult rat, to a high degree of efficiency of reutilization of tissue lysine.

Table VI summarizes some of the values in the literature showing the pattern of the amino acids ingested in the United States and a few other

4 It is of interest that the lysine requirement of the human infant appears to be lower than that of the young rat.

countries. Some of these values have been calculated from the composition of the various components of the diet, others are based upon relatively short-time nitrogen balance experiments and a few are actual analytical values determined on controlled or uncontrolled regimens. If one compares the values in Table VI with those in Table V, it is apparent that by and large the U. S. diets have a pattern of amino acids very similar to the pattern required for good nutrition of other animals. The greatest discrepancies are between the results of human needs determined experimentally on adults by the nitrogen balance method. This may be due to the extreme difficulty in estimating general human needs from relatively short-time nitrogen balance data on adults, as well as the other factors mentioned earlier.

Conclusions

The overall pattern of amino acids required for tissue growth does not vary markedly among the various species of animals studied. Many of the presently available quantitative values, especially those for tryptophan, phenylalanine, methionine and glycine, may have to be modified because of the known interrelationships of these amino acids with nicotinic acid, tyrosine, methionine and serine respectively. It is possible that other analogous relationships will be disclosed.

The amino acid requirements for adult maintenance are definitely lower than those for growth. In the case of certain amino acids the maintenance requirements may be less than 10 per cent of the quantity need for growth.

In spite of the deficiencies of our current knowledge, the results of amino acid analyses of food proteins when combined with the quantitative evaluation of the needs of different animals for essential amino acids have had great value in improving the nutrition of domestic animals. This knowledge should, in the future, be of even greater value in improving the health of the human population.

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